VOLCANIC ERUPTION PLUMES ON IO: SO_2 CONDENSATION ON TINY GLASSY VOLCANIC PARTICLES. V. Cataldo and L. Wilson. Environmental Science Dept., Institute of Environmental and Natural Sciences, Lancaster University, Lancaster LA1 4YQ, U.K. (v.cataldo@lancaster.ac.uk)

Since the Voyager era, SO_2 has been detected in the Loki plume on Io [1] and has been considered as the most important gas driving volcanic eruptions on Io. The existence of other gases within erupting plumes is likely but debatable. At present, there is also a general agreement about the SO_2 being condensed within volcanic plumes before it falls down on the Ionian surface.

Here, we present a model in which the SO_2 condensation occurs on very tiny glassy volcanic particles erupted along with gases within some volcanic plumes associated with very-high temperature hot spot locations. We start by considering steady eruptions of gas and magma in the Ionian environment. The assumption of steady conditions seems to be justified by the duration of most volcanic events observed by both Voyager and Galileo imaging systems [2, 3]. We assume that the erupting magma, which may have a temperature up to 1900 K, consistent with Galileo hot-spot and plume observational data [3, 4, 5, 6], interacts with SO_2 liquid at shallow depths. This interaction determines the volatile mass fraction and temperature of the mixture of magma and SO_2 emerging from the vent: the higher the mass proportion of incorporated SO_2 (we assume that values up to at least 30 % are possible), the lower the temperature. The magma droplets/pyroclasts are very small (1 to 100 microns, median value 10 microns) due to efficient melt fragmentation, similar to that which occurred on the Moon in eruptions into a vacuum, and so are carried along initially at essentially the same speed as the expanding and accelerating gas. In general, there is a zone extending a few km radially outward from the vent (and thus unresolvable in current imagery) where the number density of magma droplets/pyroclasts is so high that the cloud is optically dense and no heat is lost [7], thus buffering the temperature while the pressure decreases with radial expansion of the gas in accordance with a continuity equation. The radial extent of this zone is a function of both the mass flux and the velocity of material leaving the vent. When the mixture ceases to be optically thick, radiative cooling begins and subsequently both the temperature and pressure decrease adiabatically, still being linked to the radial expansion through the continuity requirement. Gas expansion and acceleration of gas and pyroclasts continues until the mean free path of the gas molecules exceeds the mean particle size and the pyroclasts

decouple from the gas to pursue essentially ballistic trajectories [8] back to the surface, at some maximum range. Eventually, the gas temperature and pressure reach a combination of values that lies on the condensation curve for SO_2, and solid SO_2 then condenses onto any available pyroclasts and also onto the surface of Io. The pyroclasts will have become very cool solids quite soon after leaving the optically thick region because the time taken for even a 100 micron particle to relax thermally is only ~ 0.01 s [9]. Depending on the difference in distance from the vent at which SO_2 condenses and pyroclasts finally land, there may be time for concentric layers of SO_2 to form.

We have initially applied this model to the plume at the Pillan vent, and we note that "snow" particles of SO_2, larger than those existing within other plumes, have been suggested for this plume [10]. The maximum range of dark (at all wavelengths) deposits at Pillan is ~200 km [3] and we take this to be the maximum range of ballistic pyroclasts which have escaped being coated with SO_2; the distance from the vent at which SO_2 condensation starts on the ground, judging by the brightness structure of the upper part of the plume inferred from HST observations [10], appears to be ~150 km. Various combinations of erupted mass flux and magma/SO_2 mixing ratio can explain the radial extent of the features seen at Pillan: the upper table below shows a representative set of examples which imply a mass flux within a factor of 3 of 10^7 kg/s.

The optical characteristics of the Pele plume can be matched by a plume either consisting of pure gas [11] or very small scattering particles with maximum sizes of 0.08 μm [10]. Preliminary attempts to simulate the Pele plume using our model with small particle sizes appear to require larger mass fluxes and larger amounts of incorporated SO_2 than at Pillan.

Through the use of computer simulations, we intend to better describe the trajectories of the particles and the process of SO_2 condensation within the plume itself as a function of these paths. We also want to extend our analysis to other gas species, like S_2, which has recently been detected in the Pele plume [3]. Our new model will also define the likely conditions for transitions between different volcanic eruption styles to occur.

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Tables illustrating the combinations of erupted magma mass fluxes and amounts of incorporated near-surface SO_2 ("gas mass proportion") which can produce deposits comparable to those from the Pillan (upper table) and Pele (lower table) eruption sites. The Pele deposit is more extensive and the Pele plume is somewhat cooler. Note: "cond." refers to the onset of condensation of SO_2; opaque refers to the optically dense zone near the vent within which conditions remain essentially isothermal.

Temp. of cond. (K)	Pressure of cond. (Pa)	Distance from vent of cond. (km)	Gas mass proportion (wt%)	Magma temp. at vent (K)	Gas velocity at edge of opaque zone (m/s)	Vent radius (m)	Opaque radius (m)	Mass flux (kg/s)
110	1.0×10^{-4}	150	5	1810	600	155	2330	1.4×10^7
"	"	"	10	1730	"	169	2570	8.3×10^6
"	"	"	20	1555	"	181	2900	5.0×10^6
"	"	"	30	1360	"	200	3300	3.7×10^6
110	2.0×10^{-4}	150	5	1810	600	210	2340	2.9×10^7
"	"	"	10	1730	"	230	2600	1.6×10^7
"	"	"	20	1555	"	260	3000	9.6×10^6
"	"	"	30	1360	"	280	3600	7.2×10^6

Temp. of cond. (K)	Pressure of cond. (Pa)	Distance from vent of cond. (km)	Gas mass proportion (wt%)	Magma temp. at vent (K)	Gas velocity at edge of opaque zone (m/s)	Vent radius (m)	Opaque radius (m)	Mass flux (kg/s)
110	1.0×10^{-4}	150	30	1360	1100	140	3210	4.8×10^6
"	"	"	40	1170	"	135	3570	3.7×10^6
"	2.0×10^{-4}	"	30	1360	"	200	3430	9.4×10^6
"	"	"	40	1170	"	189	4100	7.3×10^6
110	1.0×10^{-4}	500	30	1360	1100	470	11700	5.3×10^7
"	"	"	40	1170	"	460	14360	4.1×10^7
"	2.0×10^{-4}	"	30	1360	"	670	11900	1.0×10^8
"	"	"	40	1170	"	612	14900	8.1×10^7